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ENVIRONMENTAL EFFECTS ON VLF NAVIGATION SYSTEMS (OMEGA).(U)

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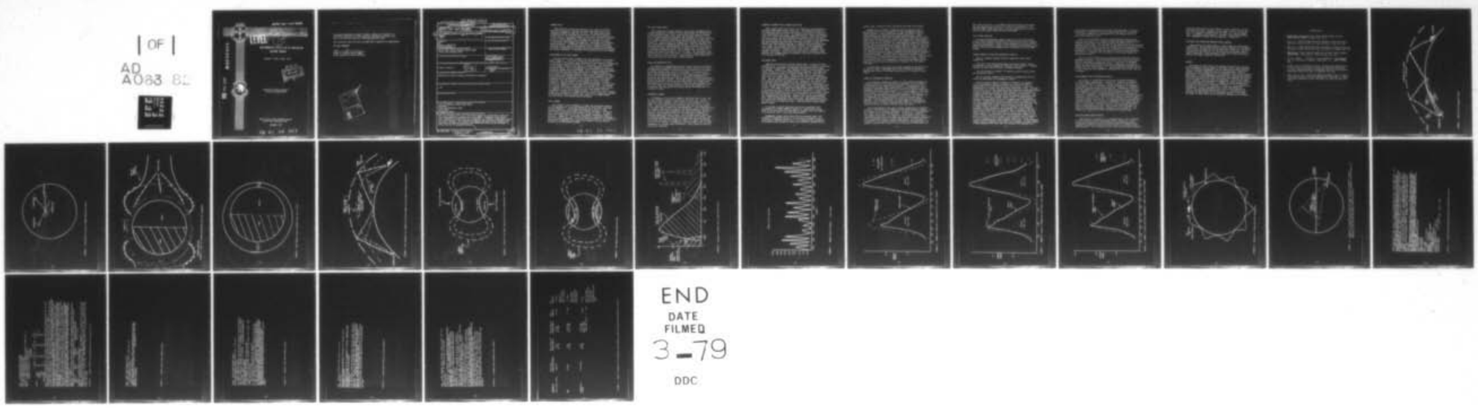

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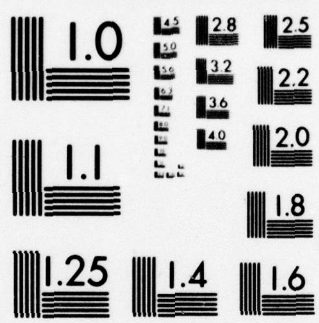

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AFGWC Tech Memo 78-004

ENVIRONMENTAL EFFECTS ON VLF NAVIGATION SYSTEMS (OMEGA)

Edward D. Beard, CMSgt, USAF

Approved For Public Release;
Distribution Unlimited

HQ Air Force Global Weather Central
Offutt AFB, Nebraska 68113

December 1978

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Thomas D. Madigan

THOMAS D. MADIGAN, Colonel, USAF
Chief, Technical Services Division

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Ionosphere
Polar Cap Absorption (PCA)
Solar Flare
Geomagnetic Storm

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Very Low Frequency (VLF) (3-30 khz) radio waves are exceptionally useful for long range navigation systems such as the OMEGA. Anomalies in the earth's upper atmosphere, specifically the ionosphere, can introduce significant errors into these systems. This technical memorandum describes these anomalies and introduces the products available from AFGWC which may help the navigator to better utilize the navigation system.

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INTRODUCTION

Radio waves in the Very Low Frequency (VLF) part of the radio spectrum are generally reliable and consistent enough for use in navigation systems on ships and aircraft. VLF radio waves travel thousands of miles following the curvature of the earth through a natural "duct". The lower boundary of this duct, the earth's surface, is only of minor consequence. The upper wall of the duct, the D-region of the ionosphere, while normally well behaved, is subject to variations, both gradual and impulsive. This paper will describe those variations. In addition, descriptions of several bulletins issued by the Air Force Global Weather Central (AFGWC) are provided. The proper interpretation of these bulletins can provide the navigator sufficient information to determine the reliability of his VLF system.

PROPAGATION OF VLF RADIO WAVES

VLF radio waves travel outwards from the transmitter via two basic modes (Figure 1). The first, called the "ground wave", will travel to distances of 500 miles or more depending on the electrical conductivity of the surface terrain over which it is travelling. The second mode, the "sky wave", permits a VLF signal to travel thousands of miles around the earth. It is the mode which is most useful for long range navigation systems such as the OMEGA. Note: Mode interference between ground wave and sky wave within 500 miles of an OMEGA transmitter will result in significant position errors if those signals are used. By monitoring the signals from two or more widely separated VLF transmitters and using triangulation, the navigator can fix his position reasonably well over any point on the earth to within a few miles (Figure 2). By using three or more transmitter signals, a simple ionospheric computer model, and time phasing techniques, the positional error can be reduced to a few tenths of a nautical mile. As pointed out earlier, the "duct" through which the VLF sky wave signal travels is composed of the earth's surface as the lower boundary and the ionospheric D region as the upper boundary. Variations in the D region height will influence the reliability of positional information provided by Navigational Computer Systems (NCS) used with the OMEGA system. The next section will address these variations.

THE D REGION

The D region of the ionosphere is formed and maintained primarily by the absorption of X rays and Extreme Ultra Violet (EUV) rays from the sun (Figure 3). Over higher latitudes the D region is also maintained by particles precipitating inwards from space. During the sunlit hours the height of the D region is near 35 miles. At night, when solar radiations are cut off, this height increases to about 55-60 miles. (Figure 4). The diurnal variation is reasonably consistent and can be easily modelled. It is the sharp variations in the reflection height due to impulsive solar flares that produce the most serious problems on VLF navigation systems.

THE SOLAR FLARE EFFECT

Solar flares are violent outbursts in the solar atmosphere where energies equivalant to several million atomic bombs are released over a short period of time. With a large solar flare, powerful streams of X rays spread outwards into space and intercept the earth in its orbit. These X rays are absorbed in the ionospheric D region resulting in an abrupt "lowering" of the upper boundary of the VLF radio duct. (Figure 5). The net result is a reduction in distance the radio wave must travel between transmitter and receiver. When the reduction in distance occurs, a transmitted pulse on the VLF signal will arrive at the receiver sooner than the NCS has accounted for, and could produce a significant positional error. With a large flare, the error on a single path could be as much as 15 or 20 miles. This phenomena, when associated with a large solar flare, is called a "Sudden Phase Anomaly" (SPA) and may last up to 4 hours. These outbursts will affect only those paths which are partially or totally sunlit.

POLAR CAP ABSORPTION (PCA)

On occasion, an exceptionally powerful solar flare will accelerate charged particles outwards from the sun. These particles can travel the earth-sun distance of 93 million miles in as little as 12 minutes, but normal transit time is from 2 to 12 hours. On arrival at the earth, these charged particles are deflected by the earth's magnetic field into the polar caps (Figure 6). The sudden bombardment of particles into the polar cap D region results in a lowered reflection height for VLF radio signals. The height reduction can produce average position errors of 5 to 6 miles on a single path, but larger events may produce errors of 12 to 15 miles. Polar cap events normally last for 2 or 3 days, but further large solar flares may compound PCA's in progress such that polar VLF circuits may be unreliable for 7 to 10 days at a time.

GEOMAGNETIC STORMS

Disturbances in the earth's magnetic field may occur at any time, but the strongest storms are associated with major solar flares. At the time of flare eruption, large volumes of low energy particles escape the solar atmosphere and arrive at the earth some 2 or 3 days later. (This arrival is often coincident with the declining phases of the solar flare induced polar cap absorption). Since these particles are charged, they are also guided by the earth's magnetic field and will dive into the upper atmosphere near the Auroral Zones (Figure 7). Normally, the charged particles are not sufficiently energetic to penetrate deeply into the D region. With stronger storms, however, a significant number of these particles can reach the D region. When this occurs the reflection height is lowered and VLF paths crossing the Auroral zones may be affected for some 3 to 5 days. Short-lived (1 hour or so) "bursts" of geomagnetic activity often occur, at times superposed on a general major disturbance. These bursts of activity are called "substorms".

SEQUENCE OF EVENTS WITH A LARGE SOLAR FLARE

When a major solar flare occurs, the sequence of events follows a generally predictable pattern (Figure 8). The immediate effects on VLF paths will occur in the sunlit areas of the earth as a result of X rays generated by the flare. The anomalous VLF effects will subside after 1 to 2 hours and normal propagation resumes. Some 2 hours after the flare occurs, the first energetic particles arrive at the earth and are deflected into the polar caps. With the onset of this phenomena, VLF paths crossing the polar caps (generally poleward of about 65 degrees latitude) become disturbed, a condition which may persist for 2 to 3 days. As the polar cap effects subside, a major geomagnetic storm begins which disturbs VLF paths to much lower latitudes (as far south as 45-50^{o}). Further major flares serve to compound events already in progress. During the three year period centered on solar maximum, the ionosphere may be disturbed in one area or another for up to 75 percent of the time.

THE SOLAR CYCLE

Impulsive solar activity follows closely what is called the solar "sunspot cycle". The sun, over the past 200 years, has shown a preference for periods of "spottiness" interspersed with periods when no spots are visible. (Figure 9). Over a period of time, a cyclical pattern with a mean period of 11.4 years between peaks is observed. The peaks have varied in magnitude from a low sunspot number near 40 (Cycle #6) to a high of over 200 (Cycle #19). During the most recent solar maximum (Cycle #20) the sunspot number reached 108 in late 1968, a near-average peak. The most recent solar minimum occurred in mid-1976 when the sun was virtually spotless for weeks on end. Cycle #21, the current cycle, is expected to be a bit more active than the mean of the previous 20 cycles, with maximum expected in late 1979-early 1980. The present point in time (winter 1978-1979) places us past midway in the rising phase of cycle 21. The number of solar flare induced VLF Anomalies are increasing in occurrence as solar activity levels rise (Figure 10). During solar minimum these disruptions occur at a rate of about one per month. During the three year period centered on solar maximum the rate of occurrence will average about once per day. However, even during solar maximum, quiet conditions may persist for several days. The appearance of only one active solar region may result in several impulsive VLF disruptions per day for up to 13 days at a time. (One full solar rotation takes about 27 days).

An increase in polar cap events also occurs concurrent with the approach of sunspot maximum (Figure 11). These events, which occur at the mean rate of one per year at minimum, will occur some 15 to 20 times per year in the solar maximum years.

Geomagnetic storms, particularly the more powerful ones, will increase in frequency from one or two per year at minimum to 35 to 40 per year at maximum (Figure 12). It is expected that ionospheric disturbances severe enough to degrade VLF navigation systems will be

present some 75 percent of the time during the solar active years.

Summarizing the effects a navigator must contend with when a major flare occurs, we can separate in time the immediate and the delayed effects. Solar flares which produce sufficient X rays to cause immediate VLF anomalies are largely unpredictable. These anomalies influence only those VLF paths which are partially or totally sunlit, and may persist for as long as four hours with a particularly large flare. As the effects due to X rays subside, the first energetic particles arrive at the earth. As these particles possess an electrical charge, they are deflected by the earth's magnetic field into the polar cap regions of the earth, and dive deeply into the D region. Polar cap effects normally begin some 2 to 12 hours after the parent flare and will persist for 2 to 3 days. VLF signals crossing the polar regions are seriously affected in phase, rendering them unreliable for precision navigation purposes. Finally, about 3 days after the major flare a large cloud of low energy particles intercepts the earth. These particles are deflected into the auroral zones by the earth's magnetic field. This process results in a geomagnetic storm which may induce VLF propagation anomalies that can spread well southward into the middle latitudes.

A single major solar flare can produce ionospheric disruptions for as long as 7 days. Compounded events, particularly during solar maximum, may result in disturbed conditions up to 75 percent of the time.

OTHER VLF PROPAGATION ANOMALIES

VLF navigation systems are subject to other anomalous propagation conditions which are not conveniently categorized. One of these is the phenomena called "wrong way propagation". Schematically, this condition arises when radio signals from a given transmitter (which propagates omnidirectionally) do not travel to the receiver along the shortest (most direct) path (Figure 13). In this example, a VLF signal which appears to be coming to the receiver along a given path is, in actuality, approaching from the opposite direction. For reasons, not yet explained, the signal expected to cross the shortest path is absorbed or greatly weakened and the "wrong way" signal becomes dominant. This condition seems to be most common on nighttime VLF paths and must be strongly considered when relying on the OMEGA, as navigation errors of several nautical miles may result.

The second anomaly occurs when a signal transmitted in a westerly direction, crosses within 45 degrees of the earth's magnetic equator, to the receiver in the opposite hemisphere. (Figure 14). The problem is most common during the nighttime hours. The physical reasons for this anomaly are unknown. It appears to be the result of an unusual interaction between the radio signal and the earth's magnetic field such that a significant change in signal speed occurs. The net result at the receiver is an apparent change in distance to the transmitter. As examples, navigational accuracy could be seriously affected along the

East Coast of the U.S. if the OMEGA signals from Liberia were used. The same problem would arise in the vicinity of Australia, if the Hawaiian OMEGA signals were used. Position fixing errors of up to 6 nautical miles could result by using these paths.

USE OF AFGWC PRODUCTS

The Space Environmental Support Branch of the Air Force Global Weather Central (AFGWC) issues several bulletins which can be applied to lessen the impacts of certain solar geophysical activities on the OMEGA navigation system. Some of these bulletins are described in this section, with specific recommendations for application to the OMEGA system.

PRIMARY REPORT OF SOLAR AND GEOPHYSICAL ACTIVITY

This is a general purpose bulletin issued daily near 2200Z (Figure 15).

Part 1A of this bulletin describes the various sunspot regions and provides a literal summary of impulsive solar activity. A general overview of solar activity levels is thereby obtained.

Part 1B provides an estimate of expected activity levels during the following 24 hours.

Part II provides analyses and forecasts of geophysical activity (Polar Cap Absorptions and geomagnetic storms).

Part III contain specific probability forecasts for impulsive solar and geophysical events. Forecasts for Class M and Class X events refer to the likelihood of solar X-Ray events. Class M is considered to be a minor, but potentially significant event. The major event (Class X) will most assuredly produce impulsive significant effects on sunlit VLF paths. The proton event forecast, while tailored for satellite systems above about 60 miles may also be translated to the probability of a PCA. The PCAF (Polar Cap Absorption Forecast) uses a color code convention (GREEN, YELLOW or RED). A GREEN forecast indicates that no region on the sun is deemed capable of producing a PCA flare. YELLOW indicates that a complex region is present on the sun which could produce a major solar flare with a resulting PCA. The word RED is used when a major solar flare has occurred and a PCA is highly likely as a result. A PCA in progress is so indicated. Generally, a high probability ($\gg$ 30 percent) of a Class X flare or a Proton Event should alert the navigator that a significant VLF disruption could occur on any partially or totally sunlit path and that close attention, including more numerous navigational checks, is required. Should such an event occur, little warning can be relayed to the flight crew, as often a sudden phase change due to solar flare X rays is accompanied by a High Frequency radio fade. If the navigator suspects that an energetic X ray event is in progress, he might request a High Frequency radio check from the airborne radio operator on a

sunlit path to a ground station at least 1000 miles away. If HF has concurrently "dropped out", a strong solar flare may be in progress. At this point deselection should begin with the longest sunlit VLF paths being deselected first.

Part IV of the primary bulletin contains observed and predicted values of the overall 10.7 centimeter (2800 MHz) solar radio emissions. A 90 day running mean of the daily values is included so that a comparison can be made. For instance, if the daily value is significantly above the mean (20 Units or more), an elevated level of solar activity can be expected, with a resulting increase in impulsive VLF disruptions. Conversely, if the daily observed value is 20 units or more below the mean (and not increasing) the likelihood of solar flare induced VLF disruptions is small.

Part V of this bulletin provides observed and predicted levels of geomagnetic activity. The value identified as AP is used as an overall index of geomagnetic activity and runs on a scale from 0 (extremely quiet) to 400 (severe geomagnetic storm). Generally, the navigator should use high latitude (60^{o} or more from the equator) VLF paths with caution when this value exceeds 25. During severe disturbances (AP, 100 or more) Anomalous VLF propagation conditions may occur as far south as 40 degrees.

HIGH FREQUENCY RADIO PROPAGATION REPORT

This report is issued daily at 0600Z and is designed primarily for the HF radio communicator. (Figure 16). However, the bulletin contains information in Parts II, III and IV which can be useful to the navigator. Part II provides a general description of ionospheric conditions observed during the previous day. Information relating to PCAs and geomagnetic storms can be extracted for VLF circuit analysis and reliability. Part III of this report contains a summary of solar flare induced ionospheric disturbances reported during the previous radio day. Generally, a strong disturbance noted on HF systems indicates disruption of VLF as well. Part IV of this bulletin contains observations and forecasts of solar 10.7 Cm radio emissions and two geomagnetic indices, K and Ap. The K value is a geomagnetic index indicating the level of activity on a scale from 0 (very quiet) to 9 (Severe magnetic storm). Ap is used in the same context as in the Primary Report of Solar and Geophysical Activity. High latitude (60^{o} or greater) VLF paths will become degraded when K exceeds 4 or Ap exceeds 25. The effects will extend much further southward with larger storms.

THE AFGWC EVENT WARNING REPORT

This bulletin is issued on an as required basis, and is triggered by any of several solar or geophysical events (Figure 17). Such activities as large Solar X ray outbursts, Polar Cap Absorptions or geomagnetic storms are sufficient justification to initiate an event warning report. Due to higher priority, time critical tasks dictated by

impulsive solar activity, this message is often transmitted one half hour after the event. However, every attempt is made to relate the activity to specific system effects (HF radio, VLF, UHF/VHF radars, etc). In addition, this message is valuable if any delayed effects (PCA, Geomagnetic storms, etc) are expected. (Figure 18).

THE SEVEN DAY OUTLOOK AND EXTENDED PERIOD REPORTS

These reports are issued weekly at 0800Z Friday and 0800Z Monday, respectively. The seven-day outlook contains estimates of the expected level of solar activity for the following week (Figure 19). The same information is provided for a 27 day period on the extended period report (Figure 20). Such information could prove useful for planning purposes for OMEGA navigation system users.

SUMMARY

This paper has dealt mainly with impulsive variations in the near earth environment and the impacts on VLF radio waves. Other phenomena such as "Wrong-Way Propagation" and the "Westerly Transmitted Signal Anomaly" are poorly understood and are not predictable. However, awareness of such problems can be of incalculable value to the navigator, particularly in those geographic areas where VLF is relied upon heavily. Predictions of large solar flares which can cause immediate VLF disruptions are possible only in terms of probability. Once a major flare occurs, however, resulting PCAs and geomagnetic storms can be predicted with a high degree of confidence. A summary of these phenomena and expected VLF variations is contained in Figure 21. It is realized the navigator may not be fully conversant in solar and geophysical terminology. Further information and lists of definitions may be found in the Bibliography publications 1 and 4. By coherent interpretation and application of the information available from AFGWC, the impact of these events on VLF navigation systems can be lessened.

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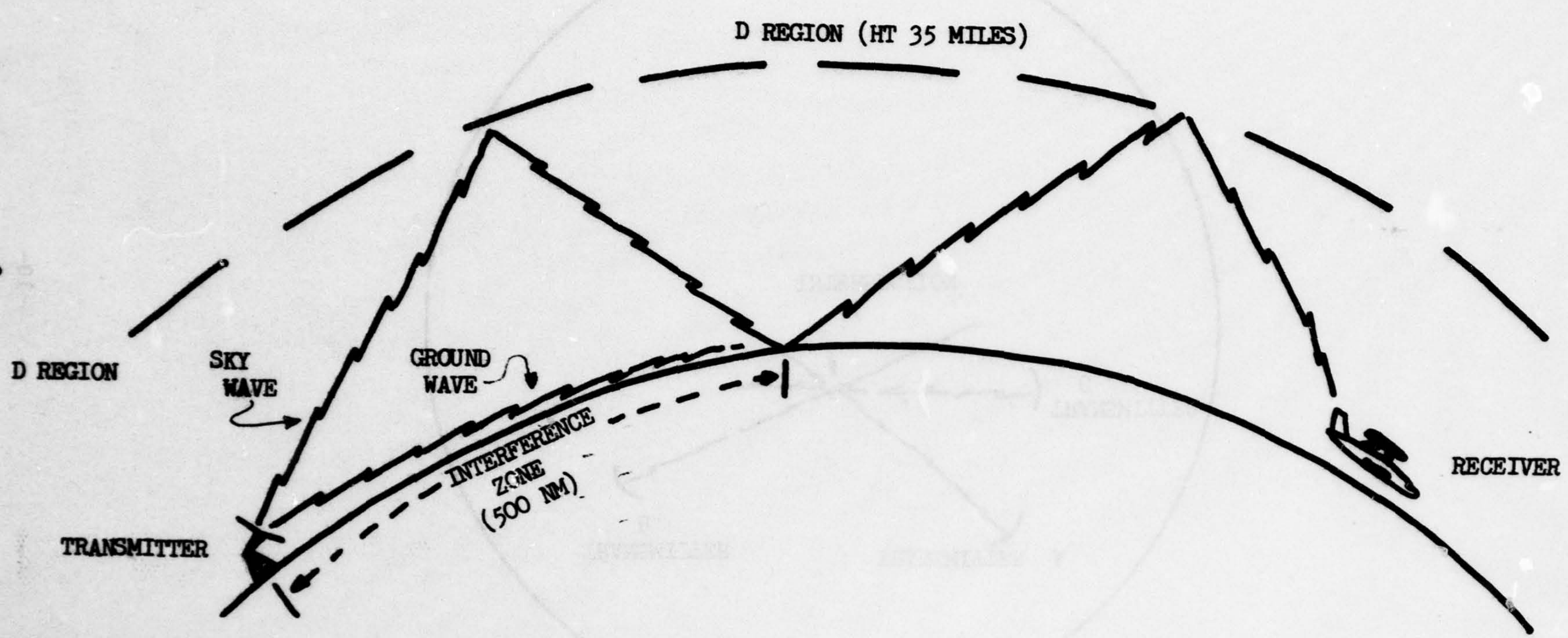

FIGURE 1. Idealized VLF Propagation Mode.

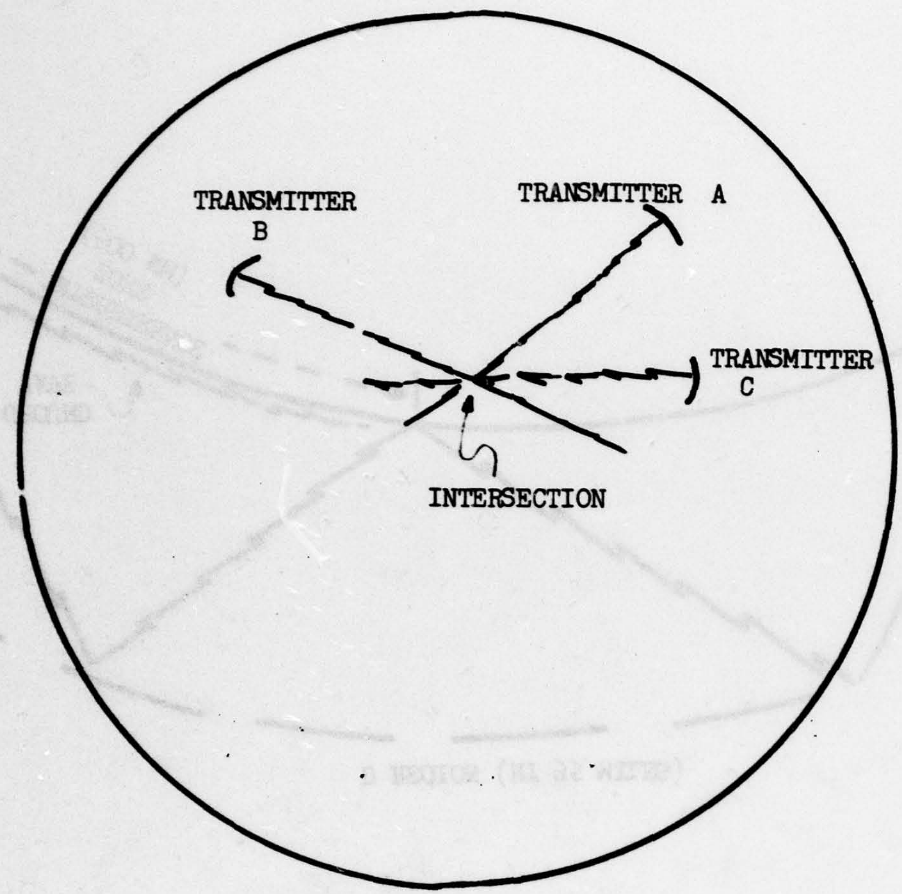

FIGURE 2. Trilateration using the OMEGA Navigation System

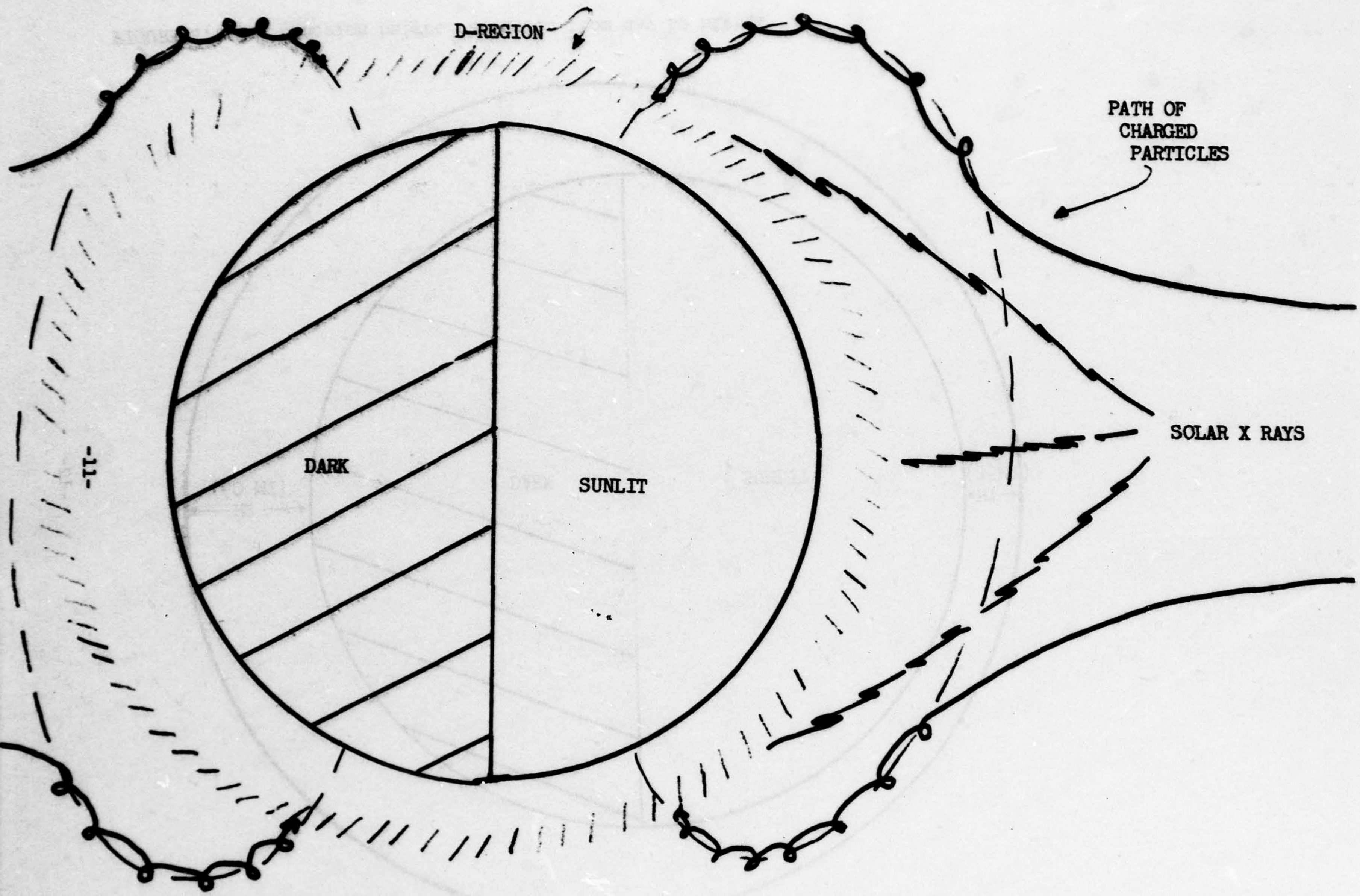

FIGURE 3. Paths of Ionizing Radiations into the Ionosphere.

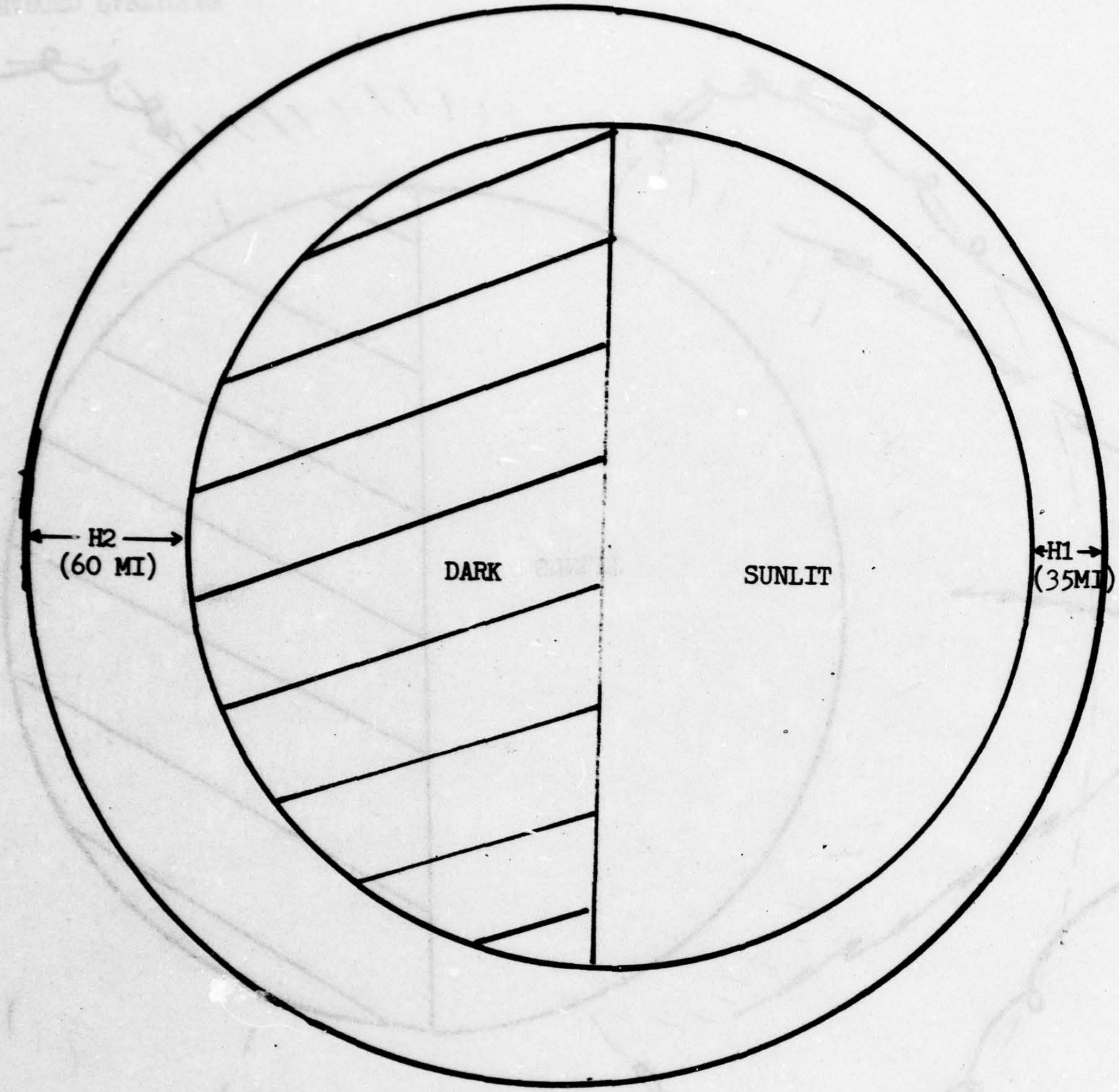

FIGURE 4. The D Region height variation from day to night.

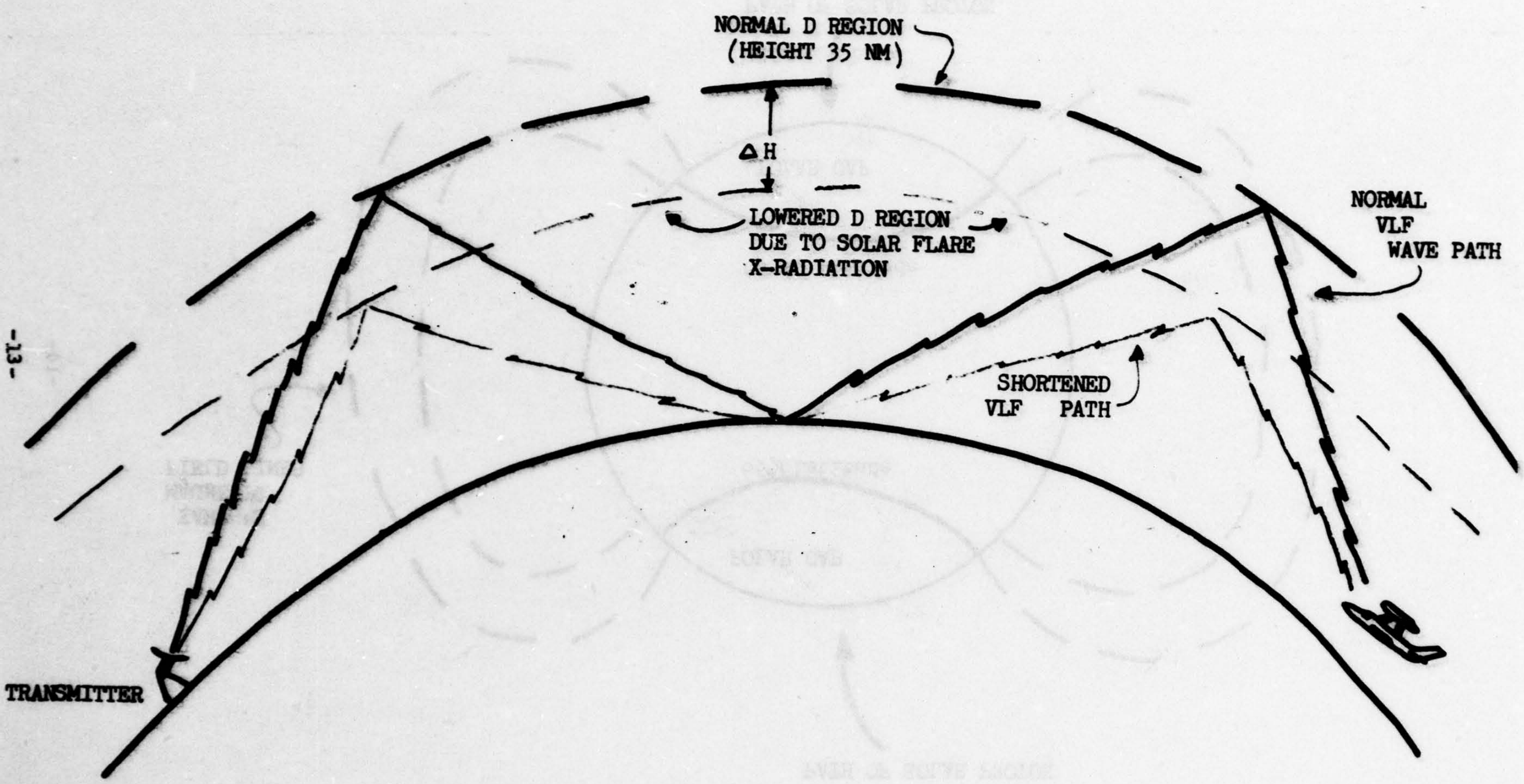

FIGURE 5. The reduction in D Region reflection height with increased ionizing radiations.

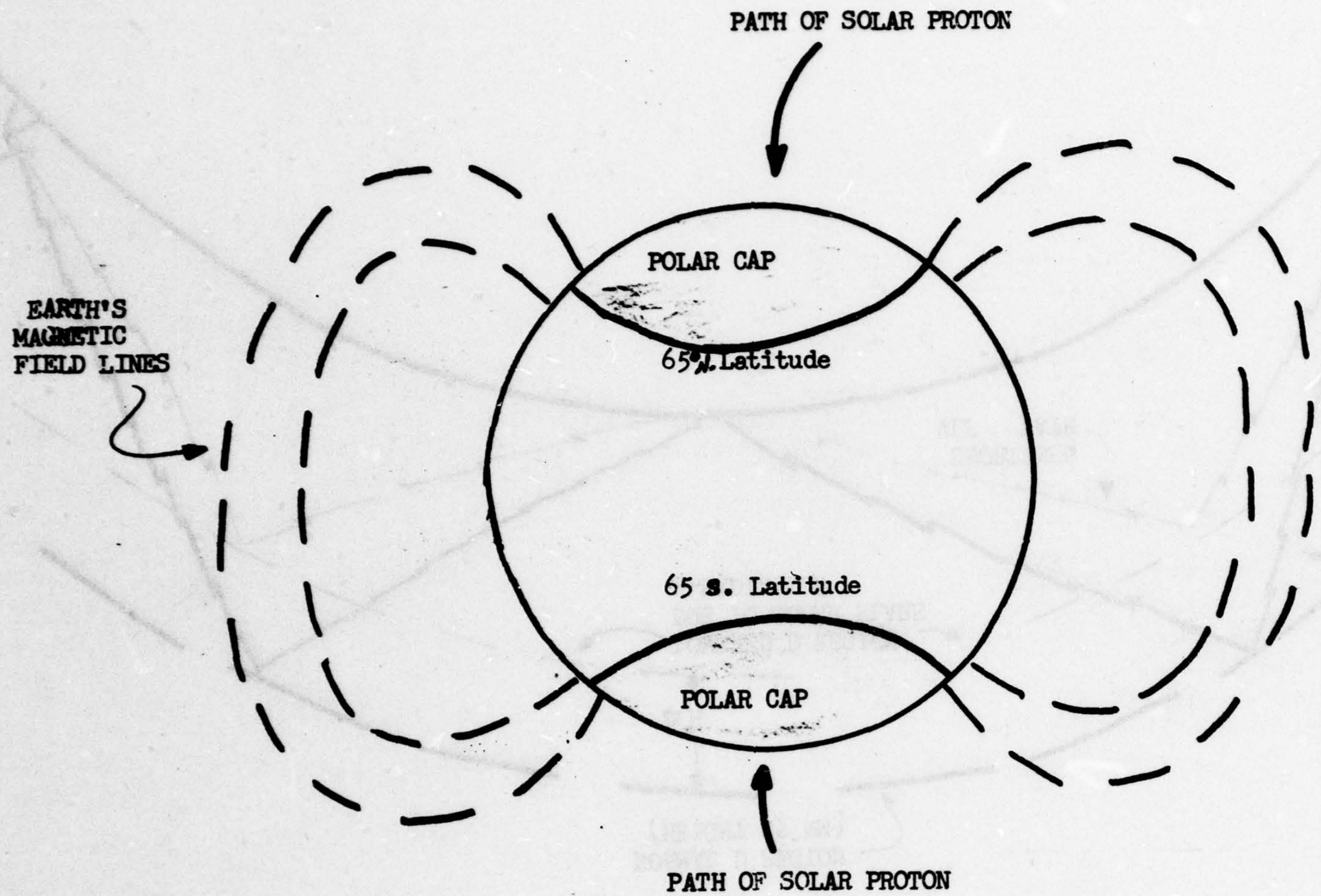

FIGURE 6. Areas of the earth affected by Polar Cap Absorptions (PCAs).

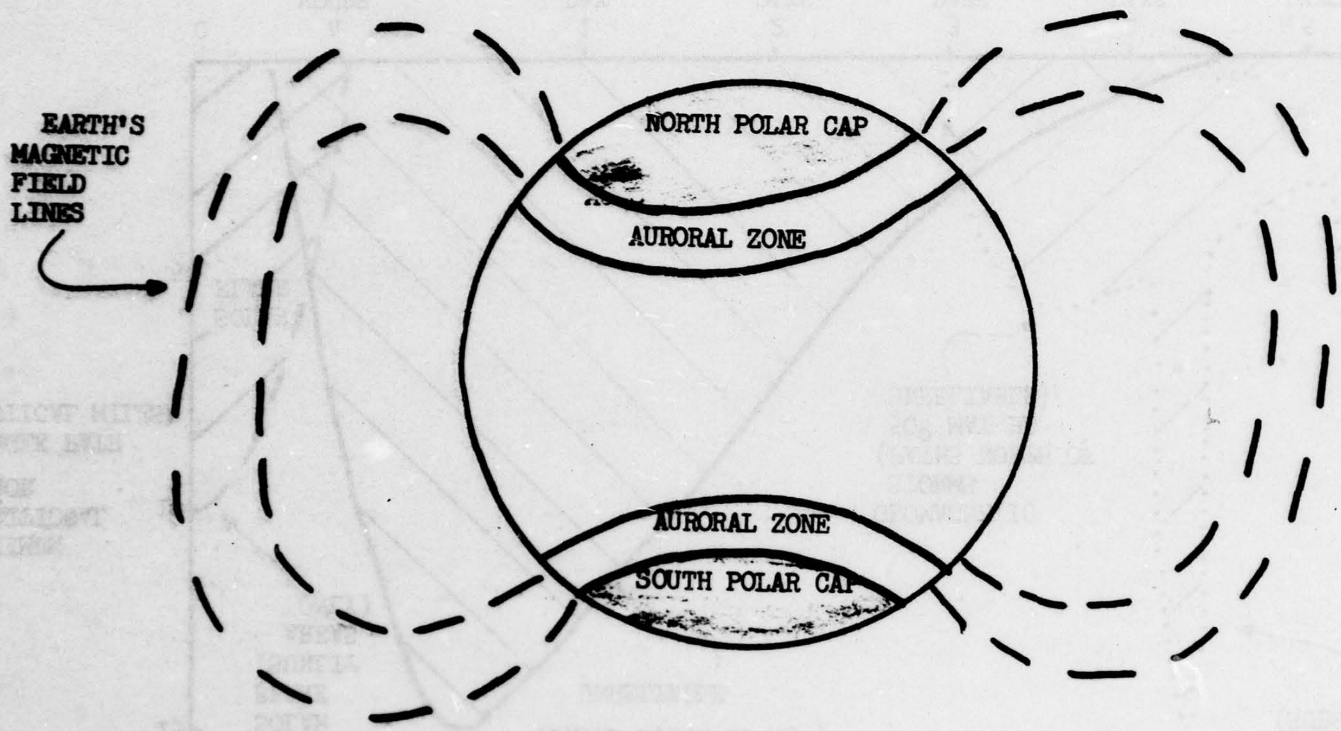

FIGURE 7. The North and South Auroral Zones.

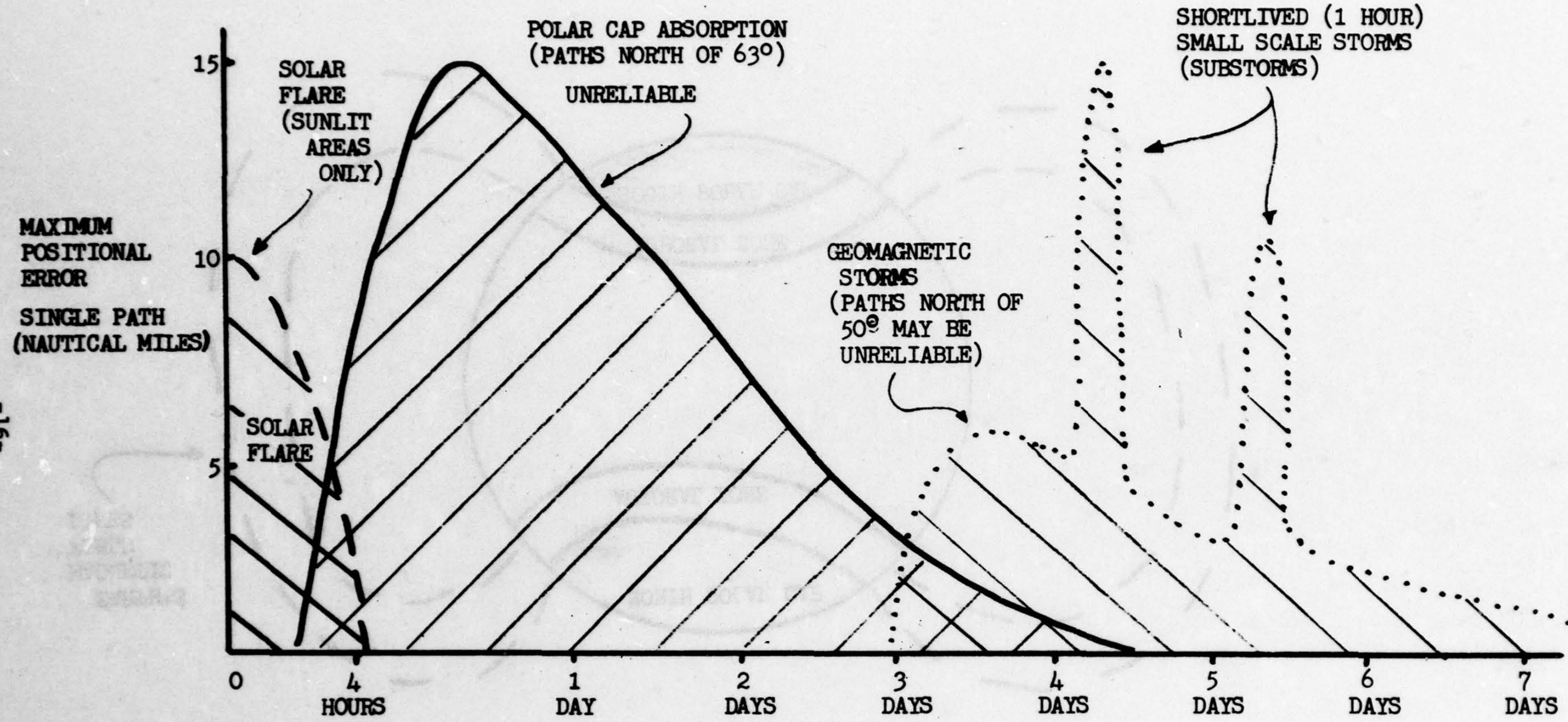

FIGURE 8. Sequence of Events with a Major Solar Flare.

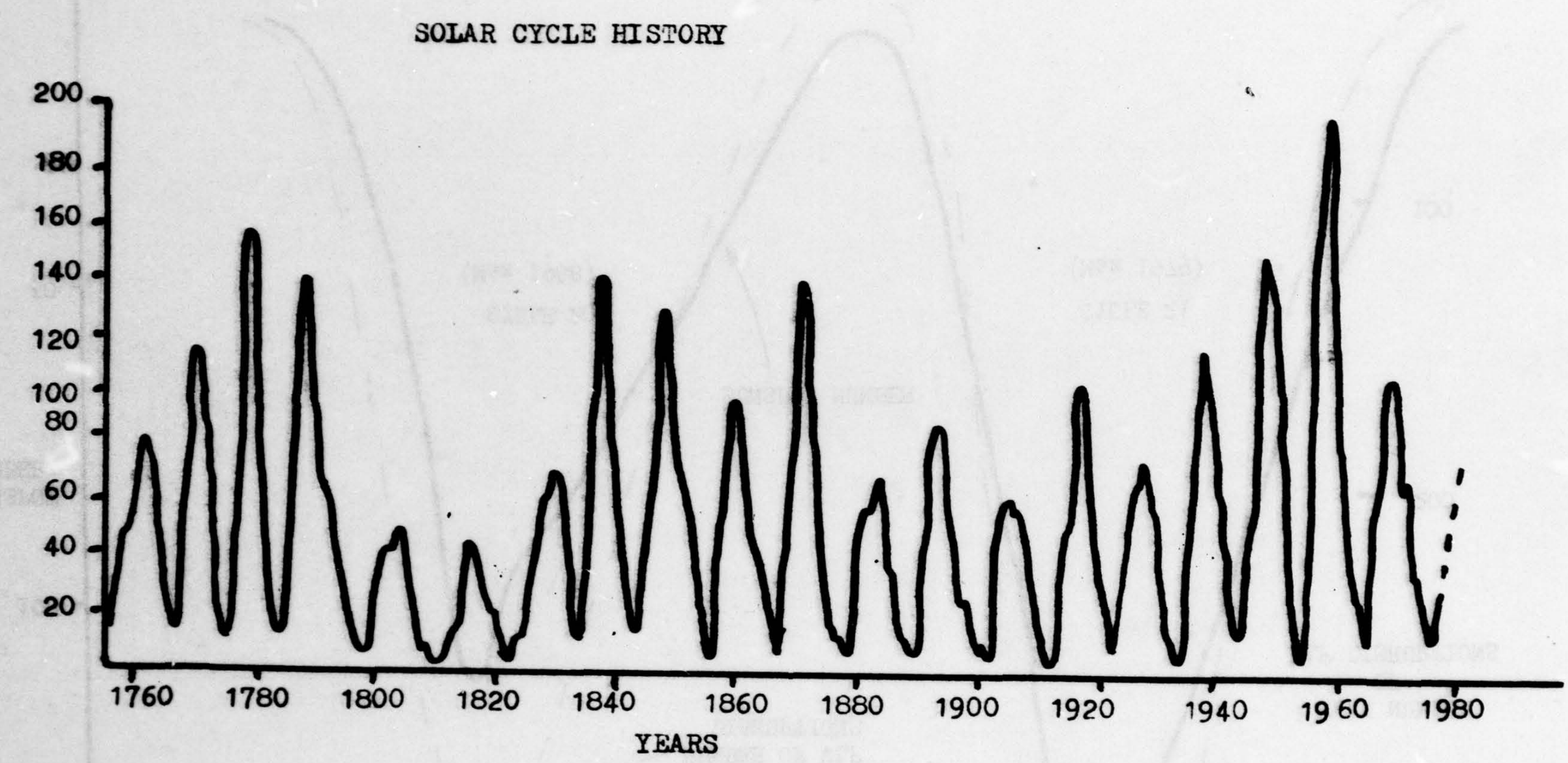

FIGURE 9. SOLAR CYCLE HISTORY (1760-1980)

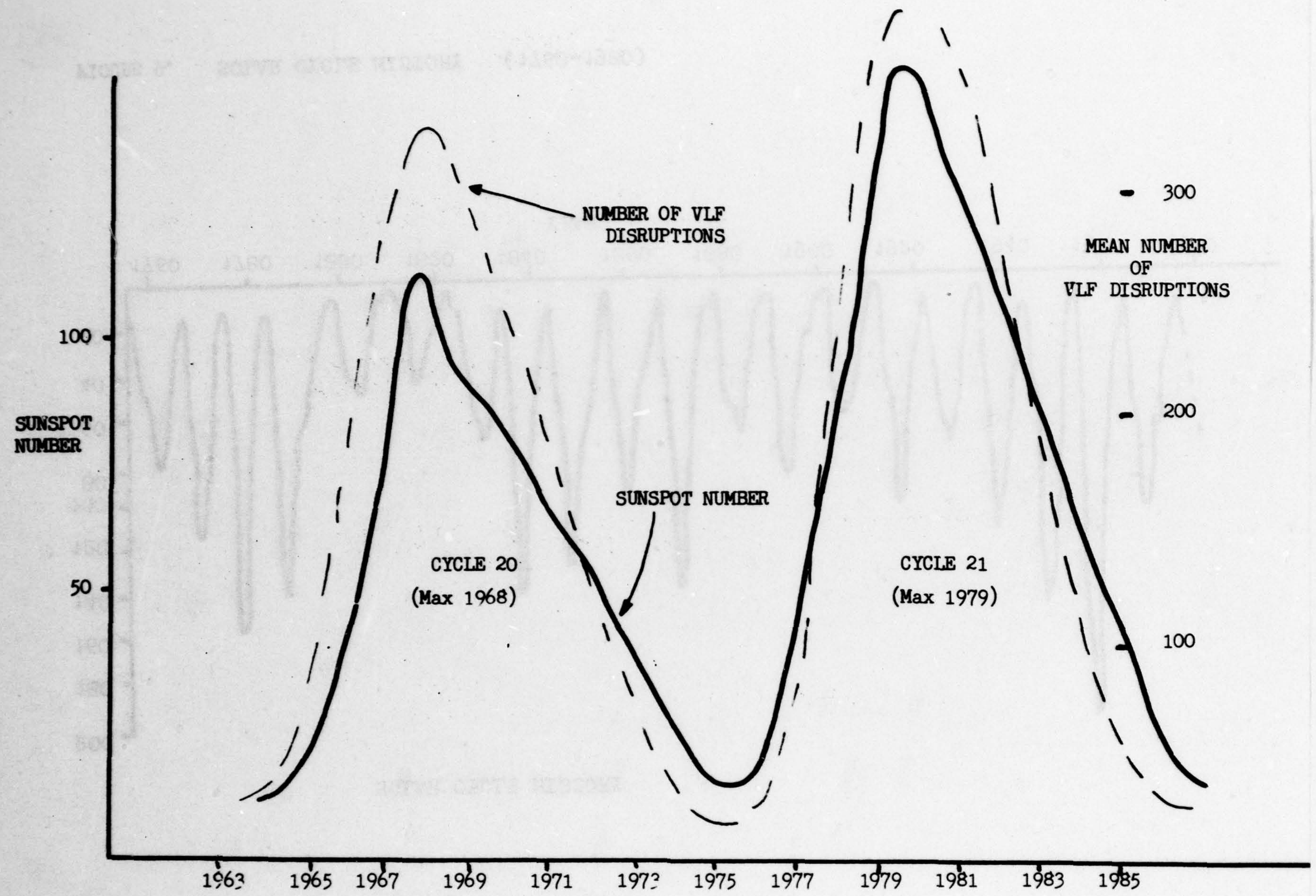

FIGURE 10. NUMBER OF IMPULSIVE VLF ANOMALIES WITH SUNSPOT NUMBERS.

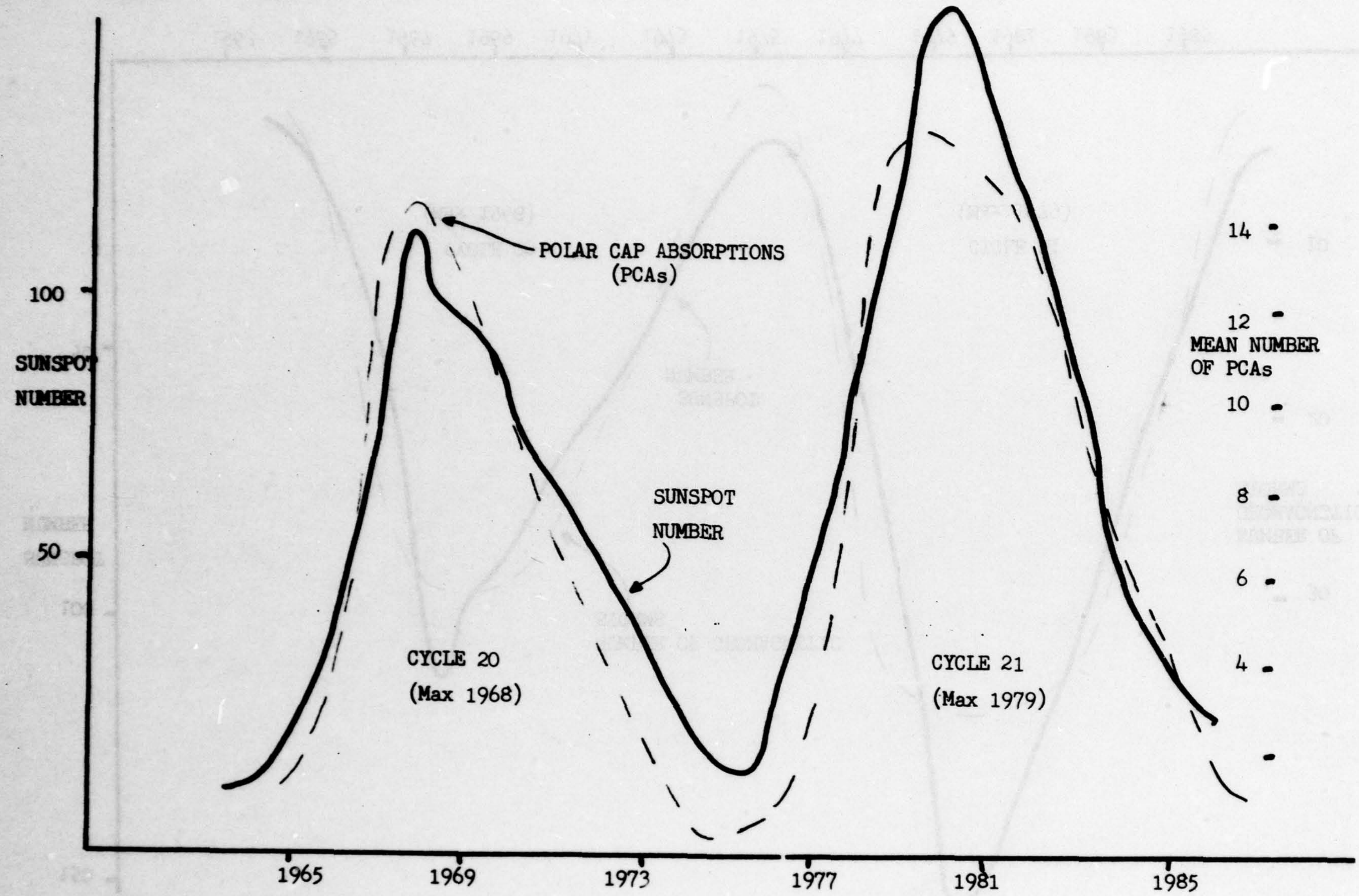

FIGURE 11. NUMBER OF POLAR CAP ABSORPTION (PCA) EVENTS WITH SUNSPOT NUMBER..

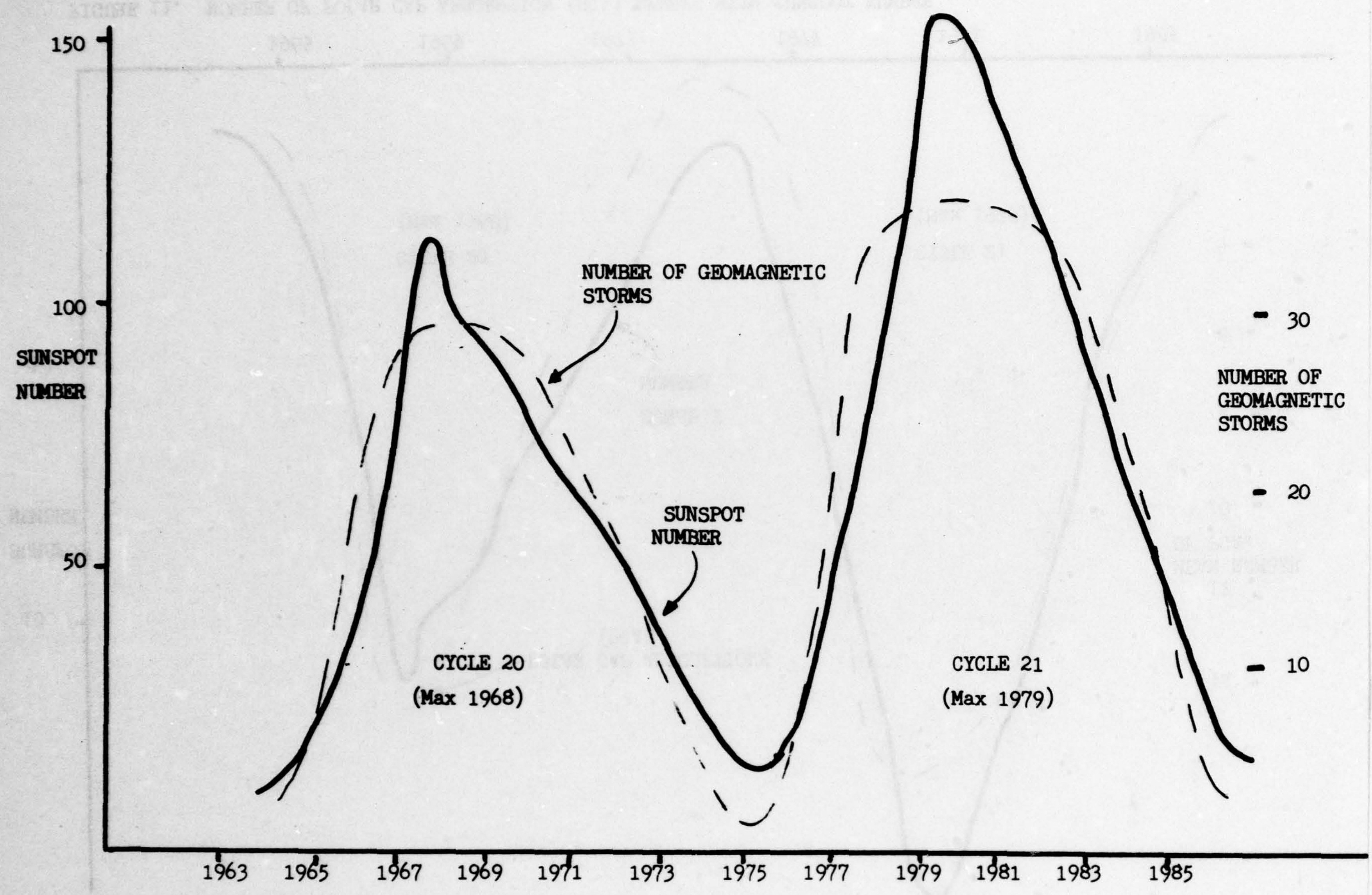

FIGURE 12. NUMBER OF FLARE ASSOCIATED GEOMAGNETIC STORMS WITH SUNSPOT NUMBER.

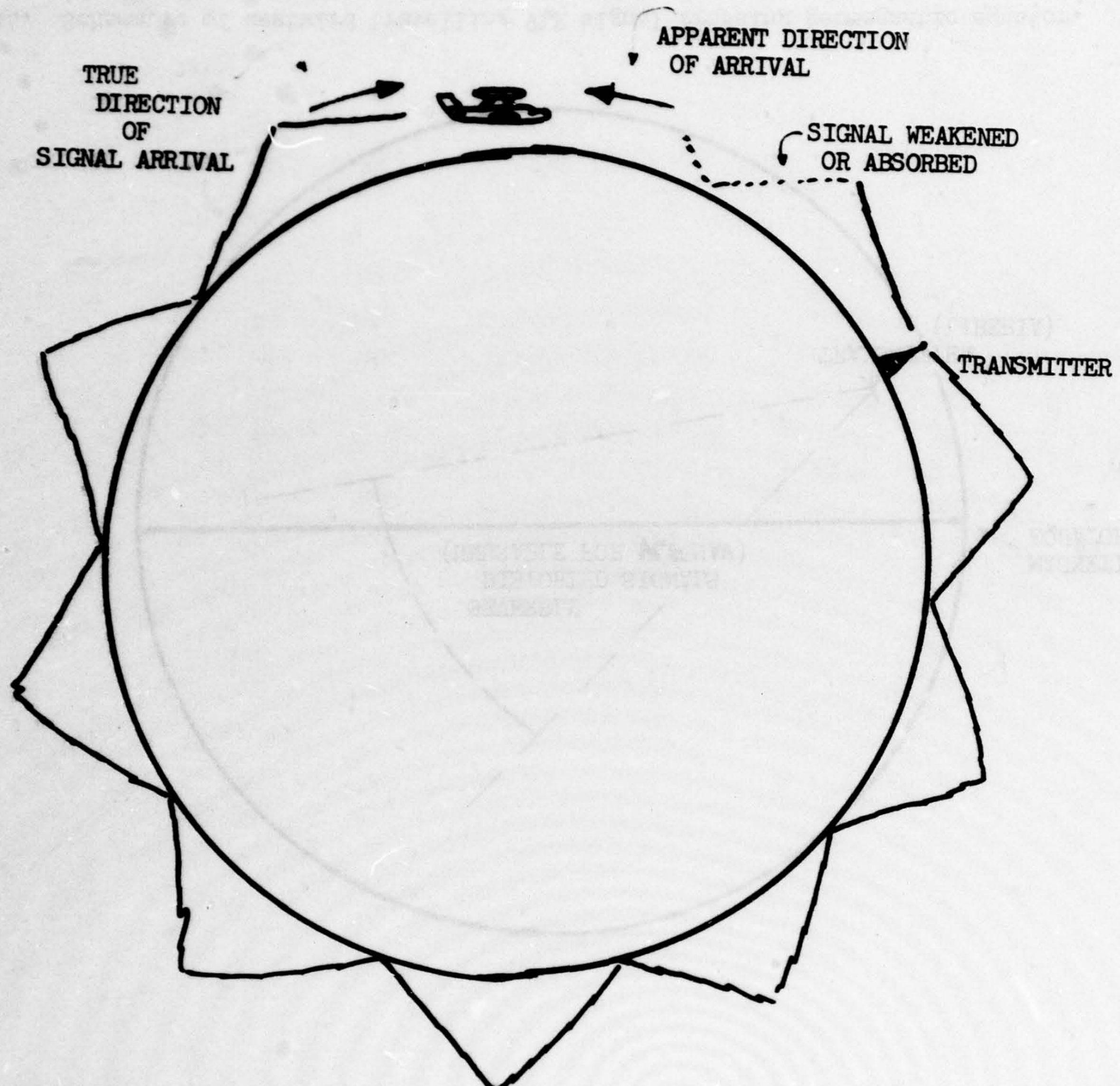

FIGURE 13. Schematic of "Wrong Way" VLF Propagation.

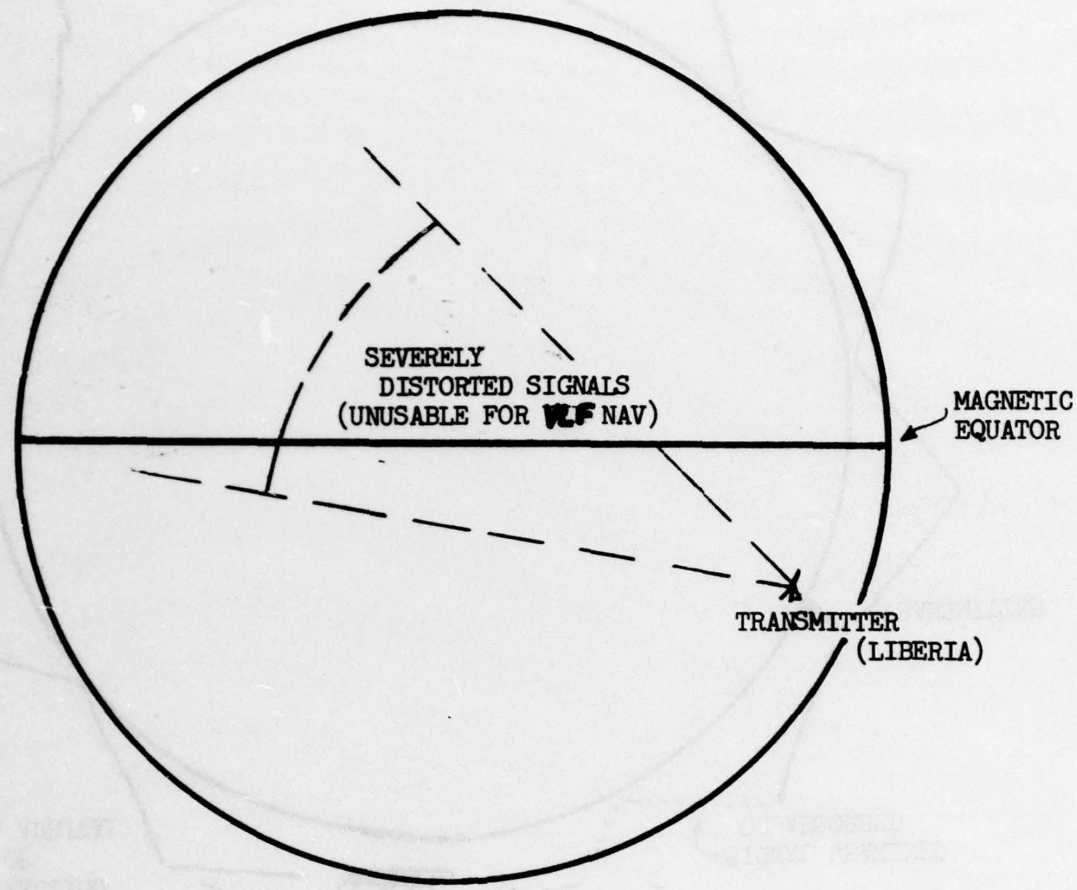

FIGURE: 14. Schematic of westward travelling VLF signal crossing geomagnetic equator. (Note: The earth's magnetic pole is offset from the geographic pole by about 11°. Therefore, they are not coincident around the earth.)

JOINT AFGWC/SESC PRIMARY REPORT OF SOLAR AND GEOPHYSICAL ACTIVITY ISSUED 22ØØZ 22 NOV 1977

IA. SOLAR ACTIVITY WAS LOW UNTIL 22/Ø93ØZ WHEN THE START OF AN X-1 X-RAY FLARE WAS OBSERVED. THE EVENT HAD A MAX TIME OF 1Ø1ØZ AND WAS OBSERVED AS A 2N OPTICAL EVENT SOME 3Ø MIN AFTER X-RAY MAX. THE FLARE OCCURRED IN REGION 939 WHICH PRODUCED A PROTON EVENT AT GREATER THAN 1Ø MEV, WHICH BEGAN AT 22/113ØZ AND IS STILL IN PROGRESS. NO OPTICAL OR ENERGETIC ACTIVITY HAS BEEN OBSERVED SINCE. IB. SOLAR ACTIVITY SHOULD BE LOW TO MODERATE. REGION 939 IS NOT CHARACTERIZED BY THOSE PARAMETERS ASSOCIATED WITH REGIONS WHICH PRODUCE HIGHLY ENERGETIC EVENTS. HOWEVER, CLASS M X-RAY EVENTS SHOULD NOT BE RULED OUT.

II. THE GEOMAGNETIC FIELD HAS BEEN QUIET. QUIET TO UNSETTLED CONDITIONS ARE EXPECTED THE FIRST 36-48 HOURS OF THE PERIOD. ACTIVITY SHOULD INCREASE ON 25 NOV WHEN A SOLAR FLARE INDUCED GEOMAGNETIC DISTURBANCE IS EXPECTED. POLAR CAP ABSORPTIONS HAVE BEEN OBSERVED SINCE 12ØØZ. ABSORPTION HAS REACHED .7 DB AND SHOULD CONTINUE THRU THE NIGHT.

III. EVENT PROBABILITIES 23-25 NOV

CLASS M 50/25/25

CLASS X 25/10/10

PROTON 30/10/10

PCAF RED

IV. OTTAWA 10.7 CM FLUX

OBSERVED 22 NOV 92

PREDICTED 23-25 NOV 91/90/89

90-DAY MEAN 22 NOV 97

V. GEOMAGNETIC A INDICES

OBSERVED FREDERICKSBURG	21 NOV 03
ESTIMATED AFR/AP	22 NOV 04/04
PREDICTED AFR/AP	23 - 25 NOV 10/10 - 12/15 - 22/25

FIGURE 15. A SAMPLE PRIMARY REPORT OF SOLAR AND GEOPHYSICAL ACTIVITY.

SUBJ: HF RADIO PROPAGATION REPORT
SPACE ENVIRONMENTAL SUPPORT BRANCH
AIR FORCE GLOBAL WEATHER CENTRAL
PRIMARY HF RADIO PROPAGATION REPORT ISSUED AT 230600Z NOV 77.
PART I. SUMMARY 230000Z TO 230600Z NOV 77
FORECAST 230600Z TO 231200Z NOV 77

		QUADRANT			
		I	II	III	IV
		0 TO 90W	90 TO 180	180 TO 90E	90E TO 0
REGION	POLAR	W3	W3	W3	W3
	AURORAL	U5	U4	U4	U4/-20
	MIDDLE	N7	U6	U6	N7
	LOW	N7	N7	N7	N7
	EQUATORIAL	N7	N7	N7	N7

PART II. GENERAL DESCRIPTION OF HF RADIO PROPAGATION CONDITIONS OBSERVED DURING THE 24 HOUR PERIOD ENDING 22/2400Z NOV 77 AND FORECAST CONDITIONS FOR THE NEXT 24 HOURS.
HF PROPAGATION CONDITIONS AT HIGH LATITUDES WERE MOSTLY FAIR TO GOOD DURING THE DAY AND FAIR AT NIGHT EARLY IN THE PERIOD. AT ABOUT 1000Z A MAJOR SOLAR EVENT OCCURRED RESULTING IN A SMALL POLAR CAP ABSORPTION EVENT BEGINNING ABOUT 1600Z. SIGNIFICANT ABSORPTION AT LATITUDES ABOVE 55 DEGREES NORTH HAS BEEN EXPERIENCED SINCE THAT TIME, BUT IS CURRENTLY SUBSIDING. THIS POLAR CAP ABSORPTION (PCA) EVENT SEVERELY DEGRADED HF CONDITIONS THROUGHOUT THE SECOND HALF OF THE PERIOD. AT AURORAL LATITUDES CONDITIONS WERE MOSTLY POOR THROUGHOUT THE PERIOD WITH MUFS DEPRESSED ABOUT 25 PERCENT IN THE SUNSET TO MIDNIGHT HOURS. MIDDLE LATITUDE CONDITIONS WERE GENERALLY GOOD WITH MUFS DEPRESSED ABOUT 25 PERCENT IN THE SUNSET TO MIDNIGHT HOURS. CONDITIONS AT LOW AND EQUATORIAL LATITUDES WERE GOOD THROUGHOUT THE PERIOD. FOR THE COMING 24 HOURS HF CONDITIONS SHOULD IMPROVE IN THE POLAR LATITUDES AS THE ABSORPTION DECREASES. FOR THE REMAINING LATITUDES UNAFFECTED BY THE PCA, HF CONDITIONS SIMILAR TO THOSE MENTIONED ABOVE SHOULD PERSIST.
PART III. SUMMARY OF SOLAR FLARE INDUCED IONOSPHERIC DISTURBANCES WHICH MAY HAVE PRODUCED SHORT WAVE FADES IN THE SUNLIT HEMISPHERE DURING THE 24 HOUR PERIOD ENDING 22/2400Z.

START(Z)	END(Z)	CONFIRMED	FREQUENCIES AFFECTED
0958	1111	YES	UP TO 19 MHZ

PROBABILITY FOR THE NEXT 24 HOURS: MODERATE.
PART IV. OBSERVED/FORECAST F 10 AND K/AP. THE OBSERVED 10.7 CM FLUX FOR 22 NOV 77 WAS 092. THE PREDICTED 10.7 CM FLUX FOR 23, 24, AND 25 NOV ARE 091, 090, AND 089. THE OBSERVED K/AP VALUES FOR 22 NOV 77 WERE 01/03. THE FORECAST K/AP VALUES FOR 23, 24, AND 25 NOV ARE 03/10, 03/15, AND 04/25.

FIGURE 16. A SAMPLE PRIMARY HIGH FREQUENCY RADIO PROPAGATION REPORT.

SUBJ: AFGWC EVENT WARNING REPORT
AFGWC EVENT WARNING REPORT ISSUED 221040Z NOV 1977.
A. SOLAR GEOPHYSICAL EVENT.
A SOLAR X-RAY FLARE BEGAN NEAR 220950Z AND PRODUCED STRONG SHORT WAVE FADES ON FREQUENCIES UP TO ABOUT 20 MHZ. TOTAL DURATION OF THE FADES WAS ABOUT 30 MINUTES.

FIGURE 17. A SAMPLE AFGWC EVENT WARNING REPORT.

SUBJE: AFGWC EVENT WARNING REPORT
AFGWC EVENT WARNING REPORT ISSUED 1500Z 22 NOV 1977.
A. SOLAR GEOPHYSICAL EVENT.
THE PROTON EVENT AT SATELLITE ALTITUDES WHICH BEGAN AT 22/1000Z CONTINUES. THE FLUX OF PARTICLES GREATER THAN 50 MEV IS DECREASING, WHILE AT OTHER LOWER ENERGY LEVELS, THE FLUX IS CONSTANT. <u>A PCA EVENT IS FORECAST TO BEGIN IN THE NEXT FEW HOURS</u>.
B. THE FORECAST FOR THE NEXT 24 HOURS FOLLOWS:
PARTICLE FLUXES SHOULD REMAIN CONSTANT FOR THE NEXT 6 TO 9 HOURS, THEN SLOWLY BEGIN TO DECLINE.
C. THE FOLLOWING SYSTEM EFFECTS ARE EXPECTED:
HF RADIO PROPAGATION CONDITIONS WILL REMAIN GENERALLY FAIR TO GOOD AT THE LOWER LATITUDES. <u>CONDITIONS ON POLAR PATHS WILL BECOME POOR TO VERY POOR WITH THE ONSET OF THE PCA</u>. <u>TRANSPOLAR VLF AND LF CIRCUITS WILL EXPERIENCE PHASE ADVANCES AND ANOMALOUS PROPAGATION WITH THE PCA. THESE CONDITIONS WILL BE MOST SEVERE DURING THE SUNLIT HOURS</u>.
SATELLITE SENSORS MAY EXPERIENCE CONTAMINATION AND ON-BOARD COMPUTER RESETS.

FIGURE 18. A SAMPLE AFGWC EVENT WARNING REPORT.

SUBJ: SEVEN DAY OUTLOOK ISSUED 0800Z 30 DEC 1977.
SOLAR ACTIVITY:
SOLAR ACTIVITY SHOULD BE MODERATE THROUGHOUT THE ENTIRE PERIOD.
GEOMAGNETIC ACTIVITY:
THE GEOMAGNETIC FIELD SHOULD BE UNSETTLED TO ACTIVE, REACHING STORM CONDITIONS BY THE END OF THE PERIOD.
HF PROPAGATION:
POLAR AND AURORAL LATITUDE PROPAGATION WILL BE FAIR DURING LOCAL DAYLIGHT HOURS AND FAIR TO POOR AT NIGHT DUE TO ENHANCED NOISE LEVELS AND ABSORPTION. CONDITIONS IN THESE AREAS WILL DETERIORATE SIGNIFICANTLY DURING THE LAST FEW DAYS OF THE OUTLOOK PERIOD. HF PROPAGATION CONDITIONS AT OTHER LATITUDES SHOULD BE GOOD EXCEPT FOR BRIEF PERIODS OF FAIR PROPAGATION DURING SUNRISE TRANSITION AT LOW AND EQUATORIAL LATITUDES.

FIGURE 19. A SAMPLE AFGWC SEVEN DAY OUTLOOK MESSAGE.

SUBJ: AFGWC EXTENDED PERIOD FORECAST ISSUED 02/0800Z JAN 1978.
FORECAST VALID FOR THE PERIOD 02 JAN - 29 JAN 1978.
SOLAR ACTIVITY:
SOLAR ACTIVITY IS EXPECTED TO BE MODERATE THROUGH THE FIRST HALF OF THE PERIOD, THEN LOW TO MODERATE FOR THE REMAINDER OF THE FORECAST PERIOD. SEVERAL REGIONS ON THE DISK AT PRESENT HAVE THE POTENTIAL FOR PRODUCING SIGNIFICANT FLARE ACTIVITY.
GEOMAGNETIC ACTIVITY:
GEOMAGNETIC ACTIVITY IS EXPECTED TO BE QUIET TO UNSETTLED THROUGH 04 JAN, THEN IS EXPECTED TO INCREASE FROM ACTIVE TO MINOR OR MAJOR STORM LEVELS FROM 05 TO 09 JAN. GENERALLY UNSETTLED CONDITIONS ARE EXPECTED FOR THE REMAINDER OF THE PERIOD.
HF PROPAGATION OUTLOOK VALID 02 THROUGH 09 JAN:
HF PROPAGATION CONDITIONS AT POLAR AND AURORAL LATITUDES WILL BE FAIR WITH SOME PERIODS OF POOR PROPAGATION AT LOCAL SUNRISE. HF PATHS CROSSING THE AURORAL AND POLAR LATITUDES MAY EXPERIENCE POLAR CAP ABSORPTION ASSOCIATED WITH SIGNIFICANT SOLAR FLARE ACTIVITY HF PATHS AT LOW AND MIDDLE LATITUDES SHOULD EXPERIENCE GENERALLY GOOD PROPAGATION CONDITIONS. EQUATORIAL LATITUDE PROPAGATION WILL BE GENERALLY GOOD WITH SOME PERIODS OF FAIR PROPAGATION DURING LOCAL SUNRISE. HF PATHS IN THE DAYLIGHT SECTORS MAY EXPERIENCE SHORT WAVE FADES DURING SIGNIFICANT FLARE ACTIVITY.

FIGURE 20. A SAMPLE AFGWC EXTENDED PERIOD REPORT.

Phenomena	Mean Rate Solar MAX $\pm$1Year	Mean Deviation Single Path	Max Deviation Single Path	Mean Duration	Max Duration
Major Solar Flare	50/year	9 Km (6 Nm)	16 Km (10 Nm)	45 min	4 hours Remarks: Sunlit Paths Only; Check HF
PCA	15/year	9 Km (6 Nm)	20-25 Km (12-15 Nm)	2.0 Days	5.0 Days Polar Paths ($>$ 63^{o} LAT) Use Long Paths with Caution
Geomagnetic Storms	30-40/year	3 Km (2 Nm)	20-25 Km (12-15 Nm)	2 Days	6 Days
			Short Lived, Impulsive Events	1 hour	High Latitude Paths ($>$ 50^{o} LAT) Use Long Paths with Caution (Possible Wrong-way Prop)

FIGURE 21. TABLE OF EFFECTS TO BE EXPECTED WITH ELEVATED LEVELS OF SOLAR AND GEOPHYSICAL ACTIVITY.